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February 1994

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PROGRAM TO DEVELOP A PERFORMANCE AND HEAT LOAD  
PREDICTION SYSTEM FOR MULTISTAGE TURBINES

FORTY-FOURTH TECHNICAL PROGRESS NARRATIVE  
AND FINANCIAL MANAGEMENT REPORT

For the Period  
January 1 to January 31, 1994  
Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
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(NASA-CR-195223) PROGRAM TO  
DEVELOP A PERFORMANCE AND HEAT LOAD  
PREDICTION SYSTEM FOR MULTISTAGE  
TURBINES Technical Progress Report  
No. 44, 1-31 Jan. 1994 (PWA) 6 p

SECTION I  
INTRODUCTION

Flows in low-aspect ratio turbines, such as the SSME fuel turbine, are three-dimensional and highly unsteady due to the relative motion of adjacent airfoil rows and the circumferential and spanwise gradients in total pressure and temperature. The systems used to design these machines, however, are based on the assumption that the flow is steady. The codes utilized in these design systems are calibrated against turbine rig and engine data through the use of empirical correlations and experience factors. For high aspect ratio turbines, these codes yield reasonably accurate estimates of flow and temperature distributions. However, future design trends will see lower aspect ratio (reduced number of parts) and higher inlet temperature which will result in increased three-dimensionality and flow unsteadiness in turbines. Analysis of recently acquired data indicate that temperature streaks and secondary flows generated in combustors and upstream airfoils can have a large impact on the time-averaged temperature and angle distributions in downstream airfoil rows.

The objective of the program is to develop 'closure-models' that will permit predictions of time-averaged effects of unsteadiness in multistage turbines. The predictive capabilities of these closure models will be verified through design and testing of hardware in a large scale rotating rig. Generalized formulations of these closure models will enhance the state-of-the-art of turbine design procedures to allow designers to optimize the performance, life and structural integrity of turbines used in airbreathing and rocket propulsion systems in a cost-effective manner.

The technical program comprises the following effort. Closure models will be formulated by using existing unique experimental and numerical data. These closure models will provide numerical values needed for 'average-passage' solvers developed by scientists at NASA to predict effects of periodic unsteadiness on time-averaged flows in multistage machines. Computational Fluid Dynamics (CFD) codes with these closure models will be used to redesign a row of airfoils for the UTRC large scale rotating rig to reduce heat loads and to improve the performance of the second stator. The redesigned airfoil will be fabricated. An experimental program will be conducted to define the distribution of the heat load and aerodynamic performance of the second stator and to allow verification of the predictive capabilities of the closure models. The closure models will then be assessed for their predictive capabilities and contribution to the enhancement of the current design system.

SECTION II  
TECHNICAL PROGRESS SUMMARY

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The period of performance for this program has been extended twelve months for a new completion date of March 9, 1994.

**TASK 1 - FORMULATE CLOSURE MODELS**

The objective of this task is formulate closure models for mathematical expressions which appear in time averaged equations of motion due to the effect of periodic unsteady flows in turbomachines. Numerical and experimental data base, together with the description of the turbine which provided the basis for these closure models, will be delivered to NASA.

Status:

Physical "closure models" are being formulated that will be consistent with the system of equations describing the 3-D time-averaged viscous flow through multistage turbines as presented by Adamczyk (Refs. 1, 2). These closure models are expected to yield an improved and more physically based predictions of time-averaged effects of periodic unsteadiness on both heat load and performance than that being provided by the prediction system used in the current turbine design process. The closure models are being formulated in a three-step approach as follows:

- Step 1 (Task 1.1): Interrogation of Existing Data Base
- Step 2 (Task 1.2): Interrogation of Multirow Computations
- Step 3 (Task 1.3): Implementation of Closure Models in CFD Codes.

Work under Steps 1 and 2 have been completed. Progress made to date under Steps 1, 2 and 3 is discussed below.

Task 1.1 Interrogation of the Existing Data Base

This task has been completed.

Task 1.2 Interrogation of Multi-Row Computations

This task has been completed.

Task 1.3 Implementation of Closure Models in CFD Codes

Work directed towards completing the modification of a 2D-boundary layer code to account for the deterministic stress terms to quantify the impact of periodic unsteadiness heat loads has been delayed due to increased allocation of resources in Tasks 4 and 5.

Task 2. Design of an Airfoil Row

This task has been completed.

Task 3. Fabricate an Airfoil Row and Prepare Test Plan

This task has been completed.

**Task 4. Conduct Experimental Program**

Data acquisition under contract funding has been delayed due to rig and data processing modification and verification.

**Task 5. Assessment of Closure Models**

Effort in this area has been to ensure that the rig modifications are consistent with the remaining portion of the contract.

**SECTION III  
CURRENT PROBLEMS**

Retesting of the baseline may delay the completion of the program.

**SECTION IV  
WORKED PLANNED**

- o Continue with rig modifications and verifications
- o Continue to review and process data from the LSRR.
- o Continue analysis of baseline configuration.

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## REFERENCES

1. Adamczyk, J. J., "Model Equation for Simulating Flows in Multistage Turbomachinery," ASME Paper #85-GT-226. (NASA TM-86869), 1985.
2. Adamczyk, J. J., Mulac, R. A, and Celestina, M. L., "A Model for Closing the Inviscid Form of the Average Passage Equation System," ASME Paper #86-GT-227. (NASA TM-87199), 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		Form Approved Budget Bureau No. 104-R0011		2. REPORT FOR PERIOD ENDING AND NUMBER OF OPERATING DAYS									
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT PERFORMANCE ANALYSIS REPORT													
TO: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135		FROM: UNITED TECHNOLOGIES CORPORATION Pratt & Whitney Group Commercial Engineering East Hartford, Connecticut 06108		3. CONTRACT VALUE									
1. DESCRIPTION OF CONTRACT		a. TYPE Cost Reimbursement (R&D)		a. COSTS									
c. SCOPE OF WORK Program to Develop a Performance and Heat Load Prediction System for Multistage Turbines		b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NAS3-25804		b. FEE									
		d. AUTH. CONTR. REF. (Signature) DATE 10/27/93		5. BILLING									
				b. INVOICE AMTS BILLED									
				b. TOTAL PYTS REC'D									
6. REPORTING CATEGORY		11. TECHNICAL ASSESSMENT OF PROGRESS		b. TECH & COM - PLETED									
		a. SCHEDULE AND STATUS		1994									
		1993											
		J	F	M	A	M	J	J	F	M	A	M	J
TASK 1 - FORMULATE CLOSURE MODELS (COMPLETED)													
1.3 Implementation of the Closure Models in CFD Codes													
TASK 2 - DESIGN OF AN AIRFLOW ROW (COMPLETED)													
TASK 3 - FABRICATE AIRFOIL ROW AND PREPARE TEST PLAN													
3.1 Aerodynamic Hardware													
TASK 4 - CONDUCT EXPERIMENTAL PROGRAM													
4.1 Aerodynamic Performance Data													
4.2 Heat Transfer Data Base													
TASK 5 - ASSESSMENT OF CLOSURE MODELS													
5.1 Aerodynamic Performance Prediction Capability													
5.2 Heat Load Prediction Capability													
5.3 Prediction Capability for Deterministic Stresses													
TASK 6 - Reporting													
Monthly Report													
Final Report Draft													

NASA FORM 333P SEP 71

Baseline Plan Identification (Col. 7a): Revision No. \_\_\_\_\_, Dated \_\_\_\_\_

NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

NASA APPROVED

SCHEDULE DATE